The Hype, Fantasies and Realities of Aquaculture Development Globally and In Its New Geographies

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> We both support sustainable aquaculture practices. However, we should be cautious with the hype we are subjected to daily. We have a collective responsibility to identify, and denounce, the Silver Bullet Solution Salespersons, remembering that in between periods of promising the Moon, there are painful "purgatory" periods of non-constructive regressions.

Introduction

We have been following the acceleration of the formation of non-traditional aquaculture groups and organizations and their more frequent messaging about aquaculture in the era of COVID-19. We are concerned that some of what we are reading and listening to is returning to failed parts of our past decades and is fanciful — more hype than reality — and misinformed. In addition, we are dismayed by the promotion of global aquaculture information being used to inform the basis and background for local aquaculture developments, especially in the areas of the world where we work and refer to throughout this article as aquaculture's "new geographies," i.e., almost everywhere outside of Asia where aquaculture is new and not traditional.

These new geographies are where aquaculture production remains very small and its practices relatively rare. We are well aware that over the past 2-3 decades there are fabulous new developments in new aquaculture geographies for aquaculture in Asia — Bangladesh (now world's fifth largest producer) and Myanmar (now the world's ninth largest producer) come to mind (FAO 2020) — but, from our Asian experiences, aquaculture there is so very different in its historical, social-ecological, consumer, market and political/governance contexts and settings to be almost irrelevant as models for the rest of the world.

Our aquaculture milieu is best characterized by its nearly complete absence of local education and experiences with aquaculture in nearly all of its public, social, consumer and political spaces in society. Routinely, we have to start at a grade-school level with even the most educated in society to define the word "aquaculture." Imagine if this was any other type of land-based food production. Do you always have to define the farming of broccoli as agriculture to your communities? Do you always have to define cabbage? For all the benefits we see to expanding aquaculture as a community of industries, seafood trade and aquaculture professionals and academics in organizations like the World Aquaculture Society, aquaculture in its new geographies is a miniscule part of our agriculture, natural resource and ocean economies. It is commonly tucked away, distant, hard to get to, see and experience. Besides its newness, comparable to the "pre-ancestor stage" of agriculture developments, aquaculture's specific resource needs constantly lead to social/governmental dysfunction and conflicts.

Nonetheless, almost every week the professional seafood communications and media outlets (and the mainstream ones too) announce a new, usually large-scale aquaculture development planned for a community near us, especially if we live on the world's freshwater or marine coasts. Academics routinely state in the first line of abstracts on many papers (choosing just one recent one here, Love *et al*. 2020), that "Aquaculture now produces nearly half of the seafood consumed globally."

These stories usually lead with the background to the local aquaculture developments that:

- Because of the need for food for a growing world population, we need aquaculture in your place and more so as the world's fisheries, and those locally, have collapsed; and by implication capture fisheries are unsustainable with the seas being plied and preyed upon by a dying generation employing ancient technologies. So, get on board, you misinformed! While you were eating your meat, there's been a huge growth of aquaculture as the world's fastest growing form of food production; and,
- Aquaculture has been growing so fast, the world (meaning you) now get half of its "fish" from aquaculture. Maps often are attached to these stories showing dots of aquaculture farms scattered across your coast, proof at a glance of aquaculture's massive proliferation in your region. These pronouncements are usually followed by statements or implications that it is urgent/vital to give this proliferation more space. The world needs more food so get with the program!

The regular responses we hear from the public (and we're coastal publics too) are: "What?! We didn't know about this and I don't like farmed fish anyway. The markets I know all have plenty of fish, so why is this needed in our favourite (you pick) — swimming hole, sailing/fishing/hiking/picnic area, etc. — and, What about the whales?!" (Note to reader here…we use the term "fish" as defined by the FAO (2020): "fish" includes oysters, scallops, animals, but not seaweeds…more on seaweeds below.) So, what's the problem here? Why is the public opposing aquaculture's obvious sane and more sustainable food developments/choices (to us) in these new geographies that have, according to the experts (Kapetsky *et al*. 2013, Costa-Pierce 2016, Gentry *et al*. 2017, Searchinger *et al*. 2018, Cottrell *et al*. 2019, Hoegh-Guldberg *et al*. 2019), seriously exciting, large new areas of potential for accelerated aquaculture developments?

We are of the opinion that it is partly us who are the problem. Yes, us; and the people we have educated, trained (and love); who we always called throughout our careers, the "good aquaculture people

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TABLE 1. Animal aquaculture Production by Regions and the Leading Producers (numbers in million metric tons (MMT)) (FAO 2020).

	World	*Asia*	*Africa*	*Americas*	*Europe*	*Oceania*
Inland	51.3	47.7	1.9	1.2	0.5	0.0
Marine	30.8	25.1	0.3	2.6	2.6	0.2
Total	82.1	72.8	2.2	3.8	3.1	0.2
		China (47.6)	Egypt (1.6)	Chile (1.3)	Norway (1.4)	

Notes: Marine includes coastal and brackishwater aquaculture. Less than 0.1 MMT is reported by FAO as "zero."

TABLE 2. FAO (2020) Estimates of EU and North America Animal aquaculture Production over 23 Years in million metric tons (MMT).

Years	*EU Production*	*North American Production*
1995	1.2	0.5
2000	1.4	0.6
2005	1.3	0.7
2010	1.3	0.7
2015	1.3	0.6
2018	1.4	0.7

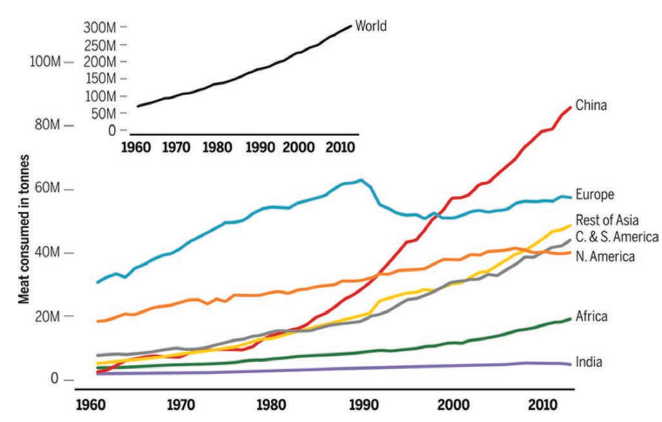

FIGURE 1. *Total consumption of meat (in million metric tons) in different regions and globally (inset) (Godfray* et al. *2018). Note that world meat consumption reached 300 million metric tons by 2010 and has continued to increase.*

in the white hats dedicated to solutions to save the world." By hyping aquaculture are we losing our abilities to obtain an accelerated social contract with publics in aquaculture's new geographies?

So, here are some alternative views from a couple of "older" aquaculture professionals that you may like… or not. Once COVID-19 is smashed; you can have your favourite beverage with us (I'll have a beer, Thierry wine), and we can talk/argue about these together. We do miss doing that with you!

Use of FAO Global Data

Every two years we relish getting in our inbox the FAO's *State of World Fisheries and Aquaculture* (FAO 2020) review (just imagine how weird that sounds to others outside of our "bubble," especially your teenagers). FAO data are fun to play with but always raise more questions than they answer, which is what they are supposed to do. Pauly and Zeller (2017) and Edwards *et al*. (2019) are among the most thoughtful scholars questioning (and helping… well, sometimes) the FAO in this regard. Even the FAO is critical of its own enterprise, as it is reliant on member countries, stating in FAO (2020), "A lack of reporting by 35-40 percent of the producing countries, coupled with insufficient quality and completeness in reported data, hinders FAO's efforts to present an accurate and more detailed picture of world aquaculture development status and trends."

Thus, we use FAO data as a general guide only. Too many of our colleagues and decision-makers use them as gospel or use them to color in the background and basis of their studies or actions, and at worse they are used to inform local decisions. These dysfunctions, plus new, emerging forms of aquaculture fantasy and hype mixed with the older ones versus what we see as reality are what we'd like to explore in this article.

Five Local-to-Global Reality Checks in Animal Aquaculture

Reality Check #1: Animal aquaculture is not growing everywhere.

Ocean food production is estimated to comprise only 4-6 percent of all human foods today (Costa-Pierce 2016). Costello *et al*. (2020) estimated that ocean foods represented 17 percent of the current production of edible meat. Fully 89 percent of all global animal aquaculture production is in Asia (60 percent of global aquaculture is in China), with only 3 percent in Africa, 4 percent in Europe, 5 percent in the Americas and virtually nothing in Oceania. Seven of the top ten aquaculture producing nations in the world are in Asia (China, India, Indonesia, Vietnam, Bangladesh, Myanmar and Thailand). FAO (2018, 2020) data show that for all of the billions of dollars/euros invested, aquaculture production has not increased in the EU (Norway is not part of the EU), the Americas, nor in Oceania; really nowhere else at a scale to get the attention of policymakers or the world outside of Asia (Tables 1 and 2). The USA and Canada are minor producers ranked number 16 and 20 in the world in 2018 (FAO 2020, OECD 2020). Exceptions in the "new geographies for aquaculture" over the past 2-3 decades are Norway, Chile and Egypt. Do they point the way as examples for the future in aquaculture's new geographies?

TABLE 3. Top Sixteen Species Groups in Global Animal Aquaculture in million metric tons (MMT) (FAO 2020).

Ranks	*Groups of Species*	*Total Production (MMT)*
1	Oysters	5.8
2	Grass carp	5.7
3 tie	Indian major carps	5.0
3 tie	White legged shrimp	5.0
5	Silver carp	4.8
6	Tilapia	4.5
7	Common carp	4.2
8	Manila clams	4.1
9	Bighead carp	3.1
10	Goldfish carp	2.8
11	Other freshwater fish	2.5
12	Atlantic salmon	2.4
13	Asian catfish	2.3
14	Scallops	1.9
15	Freshwater crayfish	1.7
16	Mussels	1.6

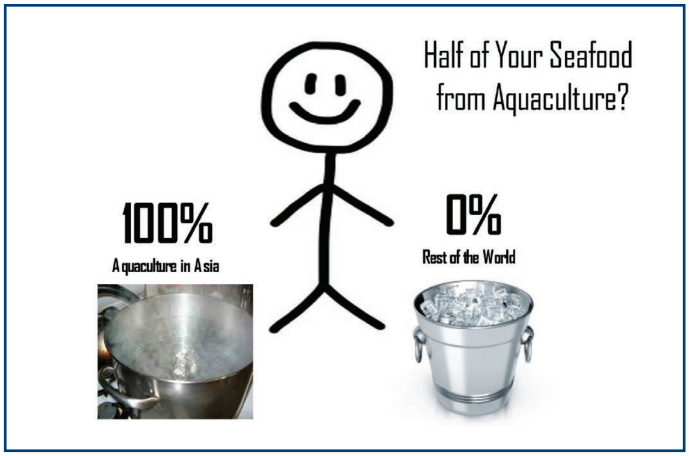

FIGURE 2. *Is half of your ocean foods coming from aquaculture? "Say you were standing with one foot in the oven and one foot in an ice bucket. According to the percentage, you would be perfectly comfortable"* -Bobby Bragan. *If nearly all global aquaculture production is from Asia and almost nothing from the rest of the world and if you are located in aquaculture's new geographies (i.e., anywhere outside of Asia), you do not get half of your seafood from aquaculture. And if you did get it from aquaculture, it's likely you would be eating a carp.*

Reality Check #2: Aquaculture is not the world's fastest growing form of protein food production.

Godfray *et al*. (2018) reviewed global trends in meat consumption and pointed to a well-established empirical relationship known as "Bennett's Law" (Bennett 1941), which states that, as people enter the middle class and become more wealthy, "their diets change from being based largely on starchy staples to diets that incorporate increasing amounts of refined grains, fruits, vegetables, meat and dairy" (Popkin 1998). As a poignant illustration of this, Godfray *et al*. (2018) documented the spectacular rise of meat consumption in China as the size of its middle class has increased (Fig. 1). There is every expectation that similar increases in meat consumption will occur with the rapidly urbanizing middle classes of Africa, Latin and South America.

Edwards *et al*. (2019) state that: "Global total edible terrestrial animal-source food (beef and buffalo, pig and poultry) dwarfed the total global production of edible aquatic animal-source food (crustaceans, finfish and molluscs from aquaculture and capture fisheries combined) in 2015, at 324 million metric tons (MMT) and just over 100 MMT, respectively. Thus, global terrestrial animal-source food production was more than three times greater than production of edible aquatic animal-source foods, and more than six times greater than the nearly 50 MMT produced by aquaculture."

Reality Check #3: The world does not get half of its fish from aquaculture.

You are not getting half of the seafood you eat from aquaculture if you live anywhere outside of Asia. Asia and China dominate all global aquaculture production for nearly every aquaculture species and system. China's aquaculture is very dynamic, evolving over more than two thousand years, and is entering its next phase with the nation's rapid economic rise and the massive urbanization of its coastal zone (Newton *et al*. 2021). China's unique place in global aquaculture makes it an outlier in our new geographies. Scientists in aquaculture's new geographies can learn much from China's lead, but the real question is: What if any of it is relevant to us?

The Naylor *et al*. (2021) review showed yet again two distinct aquaculture production worlds: the "aquaculturally-developed countries" (most of Asia) and the "aquaculturally-developing countries" (most of Africa, Europe, the Americas and Oceania). These new geographies comprise most of Mother Earth and the Oceans but represent a tiny amount of global aquaculture production.

The global data from FAO affect us locally. They are being used routinely by very smart people who should know better not to use them for such a purpose. The FAO global aquaculture production data are so bimodal that any simplistic arithmetic calculation of a central tendency is meaningless, i.e., "the mean means nothing" (Fig. 2). If the world was getting half of its "fish" from aquaculture, that fish you would be eating would be some kind of carp, as 6 of the top 16 species produced in global animal aquaculture, totalling about 21 MMT, are carps (Table 3).

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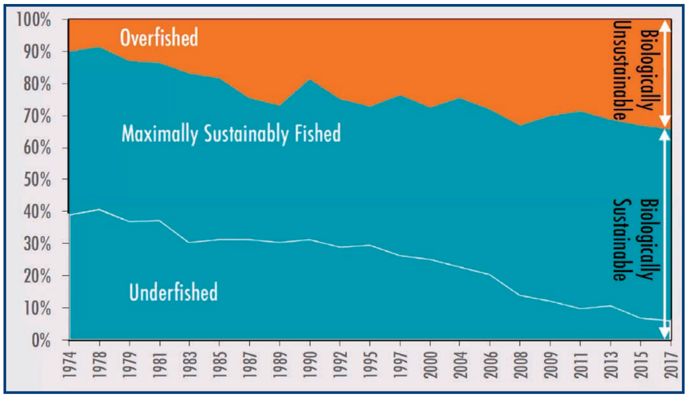

FIGURE 3. *Global capture fisheries stock status. About 70 percent of known stocks are sustainably fished or underfished. The number of overfished stocks have increased steadily over the past 20 years, deeply concerning fishing interests, markets, governance bodies, scientists and the public (Barange 2019). Note the color orange for overfished.*

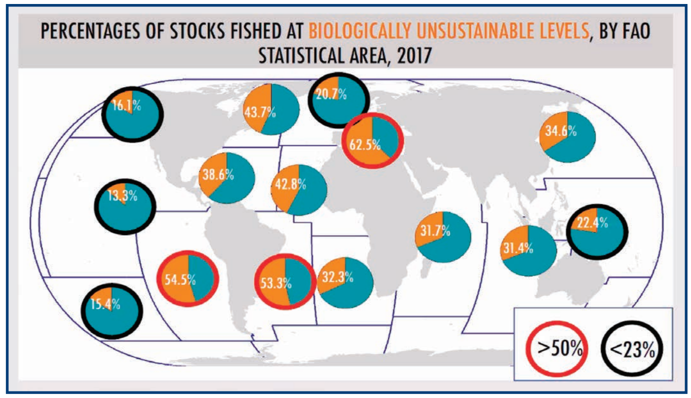

FIGURE 4. *Global capture fisheries stock status by FAO Statistical Areas. Note that all ocean areas of the world are not overfished (orange-colored segment). The most concerning areas are the Mediterranean Sea, the Southeast Pacific and Southwest Atlantic Ocean areas (Barange 2019).*

Reality Check #4: Aquaculture developments are not needed due to the collapse of the world's capture fisheries.

Edwards *et al*. (2019) state that "aquaculture overtook capture fisheries as the main source of fish for human consumption for the first time in 2013 was shown to be incorrect." Fisheries have problems but they are not the faded past of dying generations. All fishery stocks are not dead and dying everywhere despite the emotional exaggerations and lies in a recent movie on Netflix (Figs. 3 and 4). Fisheries are one of the greatest global opportunities as a low-cost renewable resource providing food for billions. There are very well-managed fish stocks that set out examples for others everywhere that are poorly managed (Hilborn *et al*. 2020). Most overfishing is in the economically developing nations, with Northern nations helping in their unsustainable exploitation (China in the Pacific, EU in West Africa), but fishery managers know well how to recover damaged fisheries technically, despite the lack of political will to do so in many places.

Aquaculture, especially coastal aquaculture, has more social-ecological constraints and equity issues to its expansion than do capture fisheries (Farmery *et al*. 2021) and aquaculture's growth is slowing down due to these (FAO 2020). Why do aquaculture promoters/advocates and scientists use the levelling off of global fisheries production to justify their local proposals for new aquaculture developments? Aquaculture developments should be justified on their own merits, for their potentials in sustainable rural development (for example, Weaver *et al*. 2020), not on global fishery data that have little to no relevance to proposed local aquaculture developments.

Professional fishery managers are working everywhere to recover damaged capture fisheries in developed and developing nations. These professionals need our engagement, understanding and technical support in all technical-social-ecological-economic innovations that can deliver more food to humanity than just aquaculture alone (Farmery *et al*. 2021). There are emerging scientifically-based ocean food production systems that merge aquaculture and capture fisheries that have the potential to change the future of both sectors, such as capture-based aquaculture opportunities (Lovatelli and Holthus 2008), and, for the environment, restoration/conservation aquaculture opportunities that interact intimately with both aquaculture and fisheries (Jones 2017, Theuerkauf *et al*. 2019). "An enormous cultural shift will be required in these areas if mariculture is to replace wild-capture fisheries as the main source of food from the ocean" (Farmery *et al*. 2021).

Recovered capture fisheries will certainly add price and volume competition to aquaculture in many regions of the world. If we can achieve this, then we can have a sophisticated discussion with policymakers and investors as to the best options for investments to deliver an accelerated amount of ocean foods to consumers. In some cases, aquaculture developments will not be economically feasible, or preferable. For example, despite large investments, cod aquaculture in the North Atlantic became uneconomic over the last two decades as rapidly expanding fisheries for cod and haddock in the Barents Sea added ~1 MMT to the world's whitefish markets (FAO 2019). This large amount of whitefish has affected USA seafood markets dramatically, especially on the East Coast, increasing the supply available (Fig. 5) due to the rapid development of lower-cost sea transportation, refrigeration and freezing systems. States the FAO (2012), "Fisheries and aquaculture interact with increasing intensity as fishers and aquaculturists shift from fishing to aquaculture and vice versa, competing in the same markets with similar products. The need to integrate planning and management of the two sectors seems vital to their future development and sustainability."

Our world needs all of the ocean foods it can produce sustainably from both capture fisheries and aquaculture in the midst of the acceleration of climate and social changes. Management conflicts and educational deficiencies between fishery and aquaculture managers need to end. Valuable products for both local and global economies and for human health and wellness that sustain ocean livelihoods will be needed from both.

Reality Check #5: Aquaculture does not need more space.

Perceptions of aquaculture among the publics in its new geographies persist that aquaculture is asking for large new spaces for proposed developments and that traditional uses will be overtaken (displaced, crowded or regulated out). Although aquaculture is worthy of getting more space because it can be among the world's most sustainable food-producing systems (Hilborn *et al*. 2018), aquaculture occupies, and plans to occupy, very small areas

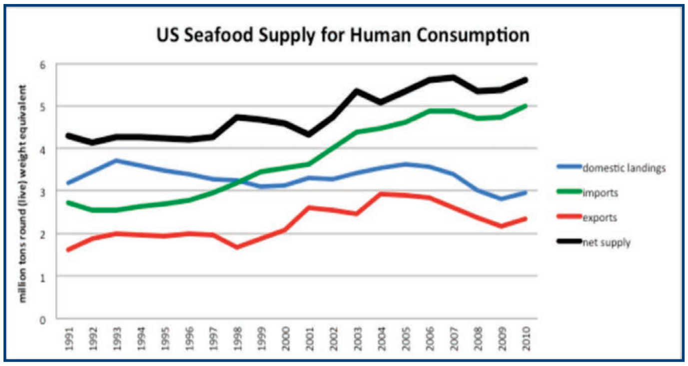

FIGURE 5. *US seafood supply has increased while domestic production has decreased. Consumers see no decreased supplies and question scientific findings due to the large imports of fisheries products to the country, the largest in the world (National Marine Fisheries Service 2017).*

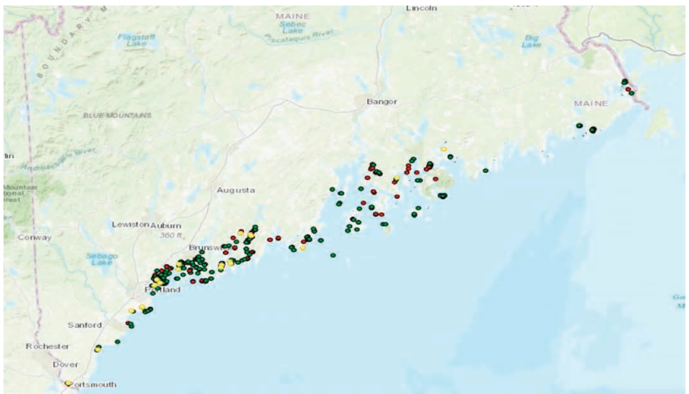

FIGURE 6. *Map of aquaculture leases and licenses on the coast of Maine, USA. The coast is 5,600 km^2 which includes bays, inlets, and estuaries. Most of the green dots on this map are tiny, 37-m^2 LPAs (Limited Permit Access) licenses that need to be renewed annually after training; they are not aquaculture leases. In 2020, there were 760 (at some point) LPAs (Flora Drury, Maine Department of Marine Resources, personal communication). So, even though it looks like aquaculture is proliferating at a rapid pace — and this is overwhelming for some in the public to see — Maine's aquaculture comprises just 630 ha (1558 aces) of active space, an area smaller than Rockland Harbor, a small town in central Maine with a total town size of 33 km^2 (Maine Aquaculture Association 2019). Green dots are active leases and licenses, yellow dots are pending, and red dots are terminated ones.*

where its developments are the most contentious, e.g. in the world's coastal zones and oceans.

In reality, aquaculture requests for space are comparable to small, well-planned "donut holes" in coastal oceans. The International Salmon Farmers Association (2018) estimated the area occupied by all of the world's very valuable salmon aquaculture at 262 km^2, or 0.00008 percent of the world's ocean area (335 million km^2). Professor Helgi Thor Thorarensen of the Arctic University of Norway says the entire Norwegian salmon aquaculture "seaprint" could fit into the area of the Oslo airport.

The public is concerned about aquaculture expansion in Maine, USA, where a widely available map (Fig. 6) shows dots of aquaculture's expansion across the coast. Most of those dots are tiny, 37-m^2 licenses that must be renewed annually after training is completed (they are not leases). In Maine, there are 630 ha (1,558 acres) of aquaculture leases (salmon, oysters, mussels, seaweeds, etc.) of the 1.3 million ha (3.4 million acres) available. All of the leased area is used. But in the case of salmon — the largest aquaculture sector by production volume and value using Maine's leased aquaculture area — approximately 30 percent of the leases are fallow due to site rotation (Andrew Lively, Cooke Aquaculture Inc., personal communication). Taken together, aquaculture comprises 0.005 percent of Maine's coastal waters. Oyster aquaculture in Maine, although expanding in area before COVID-19, remains crowded in a tiny area of the upper reaches of the state's Damariscotta River Estuary, where an estimated 70 percent of Maine's oyster industry is located.

FIGURE 7. *Seaweeds at the UNE Farm in Saco Bay, Maine, USA.*

Aquaculture adds high value for a very small space in comparison to any other food production system. And the big news seemingly announced every week — recirculating aquaculture systems (RAS) proposed throughout the world — largely occupy buildings akin to society's big box stores and service warehouses, with many being planned for abandoned infrastructure in needy rural areas suffering from job losses due to globalization and other factors.

Six Local-to-Global Reality Checks in Seaweed Aquaculture

Seaweeds (Fig. 7) are indeed amazing multi-purpose organisms, but let's be careful to not promise moons we cannot deliver. Despite being the most cultivated group of marine organisms globally, and having amazingly diverse properties useful in many applications, seaweeds have remained underappreciated and ignored until very recently. These organisms are routinely paid less attention than other inhabitants of the oceans because they do not have the popular appeal of an "emotional, charismatic species," only a few have common names that everybody can pronounce, they do not produce flowers, they do not sing like birds, and they are not as cute as furry mammals! Moreover, they suffer from a deeply rooted zoological bias throughout our education systems which makes them rarely studied and understood appropriately, thus leading to generations of ill-informed marine academics, aquaculture practitioners, resource managers, bureaucrats, policy advisors, philanthropists and investors.

If the FAO could consider seaweed aquaculture in the same way as any other component of the total world aquaculture production, and include the data of this sector directly in tables, figures and sections, with the data of the other sectors in animal

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TABLE 4. The eight genera providing the majority of the world seaweed mariculture production with "other algae" combined to make the total world seaweed mariculture production in 2018.

Red seaweeds	
Eucheuma spp.	9.4 (29.0)
Kappaphycus spp.	1.6 (4.9)
Gracilaria spp.	3.4 (10.7)
Porphyra/Pyropia spp. (nori)	2.9 (8.9)
Total red seaweeds	17.3 (53.5)
Brown seaweeds	
Saccharina japonica (kombu)	11.4 (35.3)
Undaria pinnatifida (wakame)	2.3 (7.2)
Sargassum spp.	0.3 (0.8)
Other Phaeophyceae	0.9 (2.8)
Total brown seaweeds	14.9 (46.1)
Other algae	0.2 (0.4)
Total world production	32.4 (100)

Numbers are in million metric tons live weight (FAO 2020); numbers in brackets are percentages.

TABLE 5. Major organisms produced in world mariculture in 2018.

Saccharina japonica (kombu)	11.4
Eucheuma spp.	9.4
Oysters	5.8
Penaeus vannamei (whiteleg shrimp)	5.0
Ruditapes philippinarum (Manila clam)	4.1
Gracilaria spp.	3.4
Porphyra/Pyropia spp. (nori)	2.9
Salmo salar (Atlantic salmon)	2.4
Undaria pinnatifida (wakame)	2.3
Scallops	1.9
Kappaphycus spp.	1.6
Mussels	1.6
Sinovovacula constricta (Chinese razor clam)	0.9
Penaeus monodon (giant tiger prawn)	0.8
Anadara granosa (blood cockle)	0.4
Sargassum spp.	0.3
Apostichopus japonicus (Japanese sea cucumber)	0.2

Numbers are in million metric tons live weight (FAO 2020); brown seaweeds in brown font, red seaweeds in red font.

aquaculture, instead of reducing it to overlooked footnotes at the bottom of tables, stating "excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants," it would help to correct some misconceptions, wrong interpretations of its data and avoid reaching incorrect conclusions (Chopin 2012).

Seaweed aquaculture is estimated to have produced 32.4 MMT fresh weight in 2018 for a value of US$13.3 billion (FAO 2020). This represents 51 percent of the total production of marine and coastal aquaculture. Eight seaweed genera provide 97 percent of the world seaweed mariculture production (Table 4). Two seaweed genera are the most-produced organisms in mariculture in the world (Table 5). Seven of the top 17 major organisms produced in world mariculture are seaweeds. Seaweeds were the first group of organisms to pass the 50-50 percent farmed/wild harvest global threshold 50 years ago in 1971, and presently represent 97 percent of the world seaweed supplies (i.e., wild seaweed fisheries provide only 3 percent). How much of this is known in the western world? Not much, because more than 99 percent of the seaweed mariculture production is concentrated in nine East and Southeast Asian countries and territories (depending on the status one grants Taiwan; Table 6).

TABLE 6. Seaweed mariculture production by major producers.

China	18.5 (57.1)
Indonesia	9.3 (28.8)
Republic of Korea	1.7 (5.3)
Philippines	1.5 (4.6)
Democratic People's Republic of Korea	0.5 (1.7)
Japan	0.4 (1.2)
Malaysia	0.2 (0.5)
China - Taiwan	0.1 (0.2)
Vietnam	0.0 (0.1)
Total Asian seaweed production	32.2 (99.5)
Zanzibar, United Republic of Tanzania	0.1 (0.3)
Chile	0.0 (0.1)
Other producers in the world	0.1 (0.1)
Total world seaweed production	32.4 (100)

Numbers are in million metric tons live weight (FAO 2020); numbers in brackets are percentages.

There is exciting, renewed interest in seaweed mariculture in the western world. It has been triggered by 1) their cultivation in integrated multi-trophic aquaculture (IMTA) systems in which they are the key component to recover dissolved inorganic nutrients, 2) the emerging understanding of the ecosystem services they provide and 3) the development of novel uses and new applications.

Within the last 5-6 years, seaweeds seem to have suddenly become the topic of the kind of hype and fantasies reviewed earlier for animal aquaculture in its new geographies by people who are (re-)discovering them. They are waving them around as the panacea to all our problems: climate change, fuel crisis, bovine flatulence, world decarbonization and a cure for all kinds of aches, pains and diseases. In some cases, it looks and sounds very much like the reincarnation of the Snake Oil Salesmen of the California Gold Rush Era who have become "Seaweed Oil Salespersons of the Internet." These are often people who, in fact, have never studied, touched, grown or harvested seaweeds, except during the three-minute video for a social media scoop.

Many seaweed professionals in seaweeds' new geographies are involved in pilot projects that extend not only to the Tropics but also across the North Atlantic/Pacific and Arctic areas of the world (Araújo *et al*. 2021, UN Global Compact 2021).

We recall that the last time there was such an infatuation with seaweeds was in the 1970s as a consequence of the world oil crises of 1973 and 1979, when biogas (before it became biofuels) from seaweeds were to save the world! Unfortunately, all the hype around big, well-funded projects, such as the Marine Biomass Project of the Gas Research Institute of Chicago, delivered very little. No magic fuel extraction or seaweed-based fuel product went commercial, especially after oil prices decreased in the 1980s.

What followed was around 35-40 years of "purgatory" for those wanting to continue to work on seaweeds (academics or entrepreneurs). "Why do you want to spend your time studying these obscure organisms? Last time, they promised us the moon and delivered nothing. You better work on something else!" was the common refrain we heard, until very recently.

So, is this déjà vu? Have we learned anything? Will the hype and fantasy bubble burst again in a few years, and will another 40 years of purgatory ensue for another generation of seaweed scientists and entrepreneurs who still believe in the rational development of seaweeds for humanity? Having been among the few preachers in the desert over the last 40 years, we still believe in the key food and product roles and ecosystem services seaweeds can provide, and we can testify that these purgatory periods, between waves of seaweed frenzies, are very difficult to live through.

We advocate a much more realistic approach to the development of seaweed aquaculture in its new geographies — one highlighting reasons for optimism, but also recognizing the difficulties and not promising dubious moons — and denouncing claims of miracle cures for society and the environment when we see them. Moreover, these periods of purgatory could be avoided by reducing the rhetoric and sticking to the science.

Let's set the stage by first presenting facts that show why seaweeds are, indeed, amazing multi-purpose organisms, which we can use appropriately for our benefit. It is true that seaweeds have diverse properties useful in many applications from the morning (keeping pulp in suspension in your orange juice) to the evening (giving texture to your toothpaste) without you knowing they are present as ingredients/agents. That should not entirely be a surprise.

Seaweeds (and algae, in general) are what is called a polyphyletic group, i.e. they are an unnatural grouping with different ancestors and different evolutionary histories. To understand that seaweeds are a mixed bag of organisms with not too much in common we have to go back to the Greeks and the Romans in their early attempts at classifying organisms (what is called taxonomy). When the scientists of that time did not know in which group of organisms to classify a new species, they described them as *incertae sedis* (of uncertain placement). Over time, a lot of seaweeds ended up in the *incertae sedis* box, which very much resembles a box of "lost and found" mittens, hats and scarves in a school at the end of the winter; they are disparate with not much in common.

The consequences of having a name for a group of organisms with not much in common are at least two-fold: 1) Because of this high biodiversity resulting from unnatural groupings, it is not surprising that seaweeds are the sources of many compounds and have amazing properties for many applications, and 2) having very different life histories as a result of very different evolutionary trajectories, their culture techniques vary widely, from the early stages of spore and gamete cultivation, to their grow-out phases at aquaculture sites, harvesting and processing.

Farming green, red or brown seaweeds is not very different from growing chickens, kangaroos or alligators. You better know their biology, ecology, physiology, biochemistry, etc. before trying to cultivate them. Please, do not say that they are the "low-hanging fruits" of aquaculture! If they were so easy to cultivate, they would be cultivated everywhere, but that is not the case. So, there must be something else at play to be a successful seaweed farmer.

Until now, seaweeds and other extractive species have been valued only for their biomass, food-trading and ingredient values. They need to be valued also for the ecosystem goods and services they provide. These will increase consumer trust and the social/political license to operate for the aquaculture industry and give more credibility to the increasingly popular "circular economy and blue bioeconomy" approaches and an even greener approach, the Turquoise Economy and the Turquoise Revolution (Chopin *et al*. 2010).

Among the ecosystem services provided by seaweeds, we can cite (Chopin 2018, 2021a):

- Seaweeds are excellent nutrient scrubbers, especially of dissolved nitrogen, phosphorus and carbon.
- Within an IMTA system and within an Integrated Coastal Area Management (ICAM) approach, seaweeds can be cultivated without fertilizers and agrochemicals, as the fertilizers are provided by the fed component (finfish). What were previously considered wastes or by-products are then recognized as co-products from one species that can be used as recovered fertilizer and feed resources and energy by another species, considered as additional crops providing economic diversification, while bioremediation of coastal nutrification is also taking place.
- Seaweeds do not need to be irrigated as they are already in water. In different parts of the world where access to water is becoming an issue, this is a significant advantage (Jasechko and Perrone 2021).
- Seaweed cultivation does not need more arable soil and land transformation (deforestation).
- Seaweeds can be used for habitat restoration and refugia for other species (Theuerkauf *et al*. 2021).
- Seaweeds are the aquaculture component providing a net production of oxygen while the other animal and microbial components consume oxygen.
- Seaweeds can "sequester" carbon dioxide in a transient manner and contribute to slowing global warming and climate changes. By being harvested, processed, eaten or by decaying, they allow a displacement of carbon to other places and a transformation of the forms in which the carbon is associated, but one cannot talk about permanent sequestration at geological time scales. It is vital to remember the sentence from the famous French chemist and physicist, Antoine-Laurent de Lavoisier (1743-1794), to summarize the law of conservation of mass he developed: "Nothing is lost, nothing is created, everything is transformed."
- By "sequestering" carbon dioxide, seaweeds can also reduce coastal acidification. It is important to understand that coastal acidification is not only a story of carbon dioxide because tremendous nutrification of coastal waters is also one of the major causes of coastal acidification (Wallace *et al*. 2014). Moreover, we intentionally talk about coastal acidification and not ocean acidification. It is highly

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unlikely that we will ever be able to cultivate enough seaweeds to change the pH of an ocean; however, at the level of a coast, an embayment or the intake of a shellfish hatchery, it is possible to have a significant impact.

- The IMTA multi-crop diversification approach (growing fish, seaweeds and invertebrates) could be an economic risk mitigation and management option to address pending climate change and coastal acidification impacts, thereby increasing the resilience of the aquaculture sector.
- Seaweed cultivation and IMTA systems could be associated with wind farms, in multiple use food and renewable energy parks for a reduced cumulative footprint by combining the two activities, which could bring more societal acceptance for both activities.
- Shuve *et al*. (2009) and Barrington *et al*. (2010) showed that people participating in surveys had a better appreciation of aquaculture and supported its implementation when IMTA was explained to them.

The value of these important services to the environment and, consequently, society are never accounted for in budget sheets and business plans of seaweed farms and companies. People are generally surprised when we show them, for example, that the economic value of the nutrient bioremediation services provided by the world's current seaweed aquaculture production (32.4 MMT) is between US$1.2-3.5 billion, which is about 26 percent of its present commercial value (US$13.3 billion) (Chopin and Tacon 2021).

While people and governments focus on carbon (C) trading taxes, we think that developing the concept of nutrient trading credits (NTC), in particular for the recovery of nitrogen and phosphorus, is much more important. There is more money to be made with NTC (between US$ 1.1-3.4 billion for N and US$ 51.8 million for P) than with carbon trading credits (US$ 29.1 million). Recognition and implementation of NTCs would give a fair price to seaweed and extractive aquaculture. They could be used as financial and regulatory incentive tools to encourage single-species aquaculturists to contemplate innovative practices, such as IMTA, as a viable alternative to their current practices.

Here we highlight a few forms of what we consider seaweed aquaculture "hype" and add recommendations to help reorient us towards its realities in 2021.

Reality Check #1: Seaweeds for biofuels.

Seaweeds for biofuels have been touted several times over the last few years as one of the promising materials for the fourth-generation biofuel reincarnation after three previous efforts did not take off (food crops, feedstock, microalgae). We have still not seen a commercial drop of seaweed biofuels. A reality check is necessary at several levels. It is doubtful that the surface area needed to secure the raw materials for significant biofuel production will be societally acceptable, especially in aquaculture's new geographies. Seaweed biomass production is highly seasonal while people refill at fuel stations year round. How, then, do we store a product that is highly seasonal and in which form(s)? Scaling up from laboratory experiments and pilot farms to commercial markets needs a reality check. Moreover, to be economically competitive, seaweed biofuels would have to be economically competitive with fossil biofuels used now. Why try to sell seaweeds at several cents/MT fresh weight?

The best way to move forward is to explore products from seaweeds that command much higher prices (Chopin and Tacon 2021). For our societies and for the good of our Earth, humans would be better off further developing seaweed applications with increased added value (up to more than US$ 1,000/kg dry weight), such as:

- displacing chemical fertilizers with natural fertilizers like seaweeds, produced with a much smaller carbon footprint;
- participating in the decarbonization of this world through a dietary shift towards the consumption of sustainable, safe, equitable, resilient and low-carbon ocean-based sources of foods and the mitigation of food insecurity while reducing gas emissions and carbon footprints from animal land-based food production systems (Hoegh-Guldberg et al. 2019); and
- developing nutraceuticals and pharmaceuticals to prevent and treat neurodegenerative diseases such as Parkinson disease (Giffin *et al*. 2017), a terrible burden to societies and health care systems.

Reality Check #2: Seaweeds to reduce methane emissions from cattle.

The first paper on this topic attracted a lot of attention (Kinley *et al*. 2016). The rates of methane reduction were impressive but these experiments were conducted *in vitro* (i.e., in artificial rumens) not *in vivo*. There was no real cow absorbing one gram of the red seaweed *Asparagopsis taxiformis*. We are now reading papers with experiments conducted with real cows and the results are not as rosy as with the artificial rumens. Bromoform, a halogenated compound that reduces enteric methane emissions in cows, has been found to attack the walls of cow stomachs and residues have been found in cow milk (Muizelaar *et al*. 2021).

There are two other issues. First, *A. taxiformis* (and *A. armata*) are small red seaweeds, not ubiquitous, and have complex life histories. Consequently, they can be produced with great care in academic and small-scale laboratory settings, but they will not be easy to produce at the large biomass levels necessary to feed a global cattle population estimated at about 1 billion head in 2020 (Statistica 2021). We recommend enlarging the screening to check if other seaweeds, able to be cultivated more easily in significant amounts, contain antimethanogenic compounds. For example, this is being done at the KTH Royal Institute of Technology in Stockholm, Sweden (Fredrik Gröndahl, personal communication). Second, how easy and realistic will it be to administer a daily dose of *Asparagopsis* to all of these cattle? Around 60 percent of the world's cattle are not in feedlots but ranched in free-range pastures where they are encountered infrequently, mainly when counted or branded. Even in countries where feedlots are common, cattle normally remain in a feedlot for only 3-5 months of their 36-month average production cycle.

Our opinion is that the science on using seaweeds to reduce methane emissions from cattle remains questionable. We recommend applying to this work a more rigorous use of one of the two overarching, ethical concepts of ecological aquaculture (Costa-Pierce 2021) — the Precautionary Principle.

Reality Check #3: Sinking seaweeds for carbon sequestration to the ocean bottom.

Sinking seaweeds to the deep ocean floor for carbon sequestration can, at first, look like an attractive idea. However, it is important to compare prices that can be obtained for different uses of valuable seaweeds. The present carbon tax scheme in Canada would offer CA$ 1.20/MT fresh weight (FW) of seaweeds (Chopin 2021b). Wild seaweed bed harvesters can get at least CA$ 60.64/MT FW. Seaweed farmers can access markets with prices from less than CA$ 0.127 to more than CA$ 127.03/kg FW for different applications. What would be the incentive for seaweed harvesters/farmers to harvest/grow seaweeds, then sell them at a ridiculous low price, only to see them sunk to the deep ocean floor, when they could sell them at much higher prices for other applications? Moreover, at the rate of progression envisioned by the present government of Canada for the carbon tax, it would take more than 108 years before the carbon tax matches one of the most inexpensive prices paid for seaweeds in Canada. Another point is, how, when and where would this massive seaweed biomass be stored? When asked of some of the seaweed zealots, this methodology remains evasively explained.

Furthermore, the impact(s) and role(s) this biomass will have in deep ocean ecosystems — sinking a buoyant seaweed mass to the mesopelagic zone and even deeper and its associated ecosystem impacts — are simply unknown. (Apply the Precautionary Principle again!) An argument being floated around is that e-DNA studies are showing the presence of DNA of macroalgal origin "a little everywhere." That may be, but this does not show accumulations of large amounts of seaweeds at the bottom of the ocean. We presume that, like any organic matter when decaying, pieces of seaweeds will sooner or later be mineralized and organic forms of carbon, nitrogen, phosphorus, etc., returned to their inorganic forms and be available again to the general cycle of life. This means that we are back to talking about *transient sequestration* and remembering once again the famous sentence of Antoine-Laurent de Lavoisier: "Nothing is lost, nothing is created, everything is transformed." The bottom line is that seaweeds do not seem to be suitable candidates for large-scale permanent carbon sequestration at geological time scales.

Reality Check # 4: Cultivating seaweeds at a large scale all around the planet.

About 71 percent of the earth's surface is covered with water, and if we consider nutrient concentrations and temperatures compatible with seaweed cultivation, we could come up with figures of "x" km^2 for cultivation to grow "y" MT of seaweeds, which would exceed many times present world seaweed aquaculture production. Based on decades of observing the seaweed world, we are of the opinion that decisions to grow seaweeds will be dictated mostly by societal, economic and regulatory reasons, as well as political will (or the lack of it), much more so than by models fed by academics with abiotic geospatial physico-chemical data. Like in the 1970s, a yet-to-be-proven technology-driven approach to market development is being proposed, rather than market-driven technology scaling.

Scaling is a vital issue for the nascent seaweed industry in new aquaculture geographies. Seaweed aquaculture, like the aquaculture of shellfish and other invertebrates, is generally viewed positively by many in the new aquaculture geographies, particularly by the younger generation entering this sector, who considers it as sustainable and having positive impacts on the environment. This offers an opportunity to accelerate a new social contract for aquaculture (Costa-Pierce 2010). However, this scaling needs to be gradual for the seaweed biomass to be absorbed appropriately and sustainably by the seafood markets and those of other seaweed-derived applications. Another issue with these very ambitious projects is that the proposed seaweed species are often not endemic to the regions generously drawn on maps. Not only is there no guarantee that they will grow in these locations over very large latitudinal scales but the concept of introducing non-endemic species seems of no or little concern to the proponents.

Reality Check #5: If we farm "x" km^2 of seaweeds, usually expressed as an equivalent surface area of a small country, we will be able to feed the world's population.

Large amounts of seaweed cultivation area cannot be continuous. Marine spatial planning is more necessary than ever to accommodate competing activities (e.g., navigable passages, channels, transit for other goods, communications, wind farms, fisheries, other types of aquaculture, recreational activities, etc.). In another respect, is the world population really ready to secure all its proteins, carbohydrates and lipids (not much) from seaweeds/sea vegetables? We hope that a dietary shift towards more seafood consumption will occur but this will not happen overnight (seaweeds have been the next superfood for quite a while). Moreover, a balanced and nutritious diet comes from a diversity of food sources.

Reality Check #6: Growing too many extractive species and removing too many nutrients from ecosystems could also be a problem.

At the present time, the aquaculture of extractive species, like seaweeds and invertebrates, seems to have the wind in its sails, to be the "in" fad of the day. Non-governmental organizations (NGOs) and celebrities seems to have developed a sudden love for seaweeds and sea cucumbers like never before. A few months ago, at a virtual conference from India, a speaker from Vietnam mentioned that there was a need to balance shrimp farming by more seaweed farming. A speaker from the Philippines mentioned that in some regions the cultivation of seaweeds was very intensive, leading to the consideration of developing a schedule of fallowing periods, every year or two, to let the bays replenish their nutrient levels. We are, frankly, not surprised and thought it was a question of time before such a situation was acknowledged. In Madagascar, the new poster children of "benign aquaculture," touted by several NGOs, are sea cucumbers. However, when looking at pictures of the densities of these creatures, one can only wonder how soon it will be before these deposit feeders will not have much to graze from the sediments and will need provision of supplemental feeds.

The latest fashion is to talk about restorative or regenerative aquaculture. While we wonder what needs to be regenerated, and to what state (was there ever a climax state, or nirvana, of perfect nutrient balance and habitat for all without flux?), we also wonder if there will not be a point when regenerative aquaculture will need to be regenerated, due to a large imbalance of organisms at different trophic levels being anthropogenically created? Certainly, there is a point when too much of a good thing (yes, including seaweeds and invertebrates) can be harmful.

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THE EVOLUTION OF AQUACULTURE PRODUCTION SYSTEMS AND COMMUNITIES OF PRACTICE

Ancient to 1970s	1970s to 1990s	1990s to today
Polyculture	Integrated Agriculture-Aquaculture Farming System	Integrated Multi-Trophic Aquaculture
	Integrated Aquaculture	3D Ocean Farming
	Aquaponics	Marine Permaculture
	Ecological Aquaculture	Aquamimicry
		Lower Trophic Level Aquaculture
		Restoration or Regenerative Aquaculture
		Conservation Aquaculture

FIGURE 8. *New ecological aquaculture production systems have arisen, with new monikers and labels that have attracted new communities of practice that identify themselves with these labels and innovations, not necessarily with "aquaculture."*

Recommendations from Our Realities for Aquaculture in its New Geographies

Large-scale aquaculture has evolved substantially in the past 20 years (Naylor *et al*. 2021); innovations are reported globally almost every week. In addition, new ecological aquaculture production systems have arisen with new monikers that have attracted new communities of practice that identify themselves with these innovations, not necessarily with aquaculture (Fig. 8).

However, aquaculture development has serious systemic problems throughout its Asian and new geographies. In China and India, population growth, urbanization, water shortages, pollution, and the spectacular rise of their middle classes is moving aquaculture from its traditional aquaculture geographies in ricefields and pond areas into warehouse-type buildings, recirculating aquaculture systems and inland (Newton *et al*. 2021).

Outside of Asia, aquaculture is developing in very few countries. FAO global data on aquaculture in most of the world are only fun to play with, not to use for their local context or policy-making in aquaculture (Mialhe *et al*. 2018). We ask aquaculture developers in most of the world outside of Asia…what good does it do to your work locally in aquaculture development to present the famous FAO figure showing the millions of tons of the different types of aquatic food systems that are dominated by carps? In-depth discussions of the local proposal for aquaculture by any observant person would point that out and also show that most of the world's ocean food production and employment is in capture fisheries.

Aquaculture has great potential in inland, freshwater areas where land tenure and water rights can be secured, management and waste treatment systems are more advanced, and governance systems are far more straightforward than for marine aquaculture (Edwards 2009, Edwards 2015, Belton *et al*. 2021). However, we find it unhelpful to pit the future of aquaculture as a battle for scarce resources for aquaculture as a whole vs. the mega-giant resources available for unsustainable agriculture. Once we break into camps that pit us into freshwater vs. marine aquaculture; coastal vs. offshore aquaculture; small-scale vs. large-scale aquaculture; and fed vs. extractive aquaculture, we lose our way with decision-makers. Aquaculture is the poor cousin of agriculture and will remain so in the new aquaculture geographies if we fracture more than we already are. Let's work to develop outstanding, economically viable, social-ecological examples of sustainable aquaculture systems in all of these diverse areas and create additional aquaculture wisdom for the future.

Each of these aquaculture development options has a possible future of innovations in a local context. They have possible sustainable trajectories and can also be integrated to accomplish more sustainable ways of producing aquatic proteins valuable for human health and wellness in comparison to existing, destructive, terrestrial protein systems — if any one of them received funding anywhere near the funding that goes to agriculture.

Recommendation #1

Do comprehensive deep dives into data of the fisheries and aquaculture local/regional production and trade, and the competition aquaculture will face from current and projected fisheries and ocean food imports. Document where your ocean foods are actually coming from! Use market-driven aquaculture development assessments, not technology-driven aquaculture development hopes and dreams.

Recommendation #2

Stop defining the future of aquaculture on the social-ecological collapse of fisheries. Join in with everyone you know to help recover fisheries at all levels. That means enhancing by all means fisheries restoration and management efforts everywhere. The many allied, mixed fisheries-aquaculture systems of capture-based aquaculture (Lovatelli and Holthus 2008), aquaculture enhanced fisheries, integrated multi-trophic aquaculture, and restoration aquaculture could change the very future of both aquaculture and fisheries (and protein food production).

Recommendation #3

Aquaculture management in many of its new geographies is buried in fisheries or agriculture agencies. Many areas that have abundant marine and freshwater resources suitable for sustainable development are part of an unfortunate but growing trend — an overemphasis on "marine/coastal" as "aquaculture" — and neglect the large potentials for inland aquaculture. Such structural, institutional issues need to be fixed or knowledge and governance systems for aquaculture will remain broken, with inadequate positioning of opportunities and a lack of learning between freshwater and ocean communities in aquaculture.

Recommendation #4

The FAO should stop treating the seaweed aquaculture sector as a different category, with separate tables and separate comments in different sections as this leads to a distorted view of what really constitutes the total world aquaculture and the broad contributions of aquaculture to food systems. Include seaweeds in comprehensive tables, figures, sections and chapters with the other aquaculture crops to simplify and improve the understanding of fisheries and aquaculture statistics and to avoid recurrent misconceptions about the aquaculture world.

Recommendation #5

When including seaweed production in total world aquaculture production, the total extractive aquaculture is slightly larger (51 percent) than the total fed aquaculture (49 percent). At first, one could rejoice at these numbers; however, one more time, "the mean means nothing," as it is important to remember that more than 99 percent of seaweed aquaculture remains concentrated in Asia. Consequently, extractive aquaculture needs to be more evenly distributed worldwide in an attempt at balancing fed aquaculture. It seems that, even in Asia, putting some seaweeds in shrimp operations in Vietnam, and some fish cages among eucheumatoid farms in the Philippines could be a good idea to avoid the extremes (overly eutrophic or oligotrophic conditions). This exemplifies the old adage "everything in moderation" and highlights the merits of the IMTA concept that needs to be adopted more universally for enhanced overall productivity, improved resource-use efficiency, reduced impacts on the environment and improved water quality by removing waste materials and lowering nutrient loads (FAO 2020).

Recommendation #6

Instead of going through these boom-and-bust seaweed cycles, we recommend more sustainable economic cycles in the long-term by avoiding untenable promises. The multitude of applications using seaweeds is certainly amazing, but seaweeds cannot be the silver bullet for everything. Moreover, one cannot want to permanently remove carbon from our ecosystems and produce fertilizers, feed, food, ingredients, cosmeceuticals, medicines and other high value-added products at the same time, with the same raw material, when market forces drive their uses towards the most lucrative applications in the absence of subsidies, grants and philanthropy.

Recommendation #7

Unless societies are ready to put some grand subsidy scheme in place — such as seriously increased trading taxes on the externalities not yet internalized and implementing some robustly financed trading credits to reflect the ecosystem services provided by nature and extractive aquaculture, pretty much "free of charge" thus far — there will be no financial incentives for seaweed farmers/harvesters to direct the sale of their biomass towards carbon sequestration to the deep ocean. The schemes for taxes or credits of nutrients (which include carbon as it should also be considered a nutrient) need to be seriously re-evaluated to calculate the true values of the ecosystem services rendered by some species and to those who use them. Moreover, wanting to develop seaweed biofuels is still basing our society on the C (carbon) element that we have to move away from. It is time to embrace other sources of energy, being solar, wind, hydrodynamic, or hydrogen (the H element), recognizing that, perhaps, none will be the silver bullet, but combined could be a major source of our energy needs.

Recommendation #8

We should realize that we are still in the infancy of western IMTA. Science and society need time to think and evolve. The adoption of IMTA and its key inorganic component, the seaweeds, will not happen overnight, especially in aquaculture's new geographies that presently prefers monocultures, linear processes and short-term profits. We will need patience, determination and persistence for people to see the environmental, economic and societal advantages of growing complementary species together, creating circular economy processes and seeking sustainability in the long term.

Lastly, please stop the stupid childish China bashing

These have devolved into silly, testosterone-laden trade wars and bullying and led to accelerated racism worldwide. To illustrate how stupid trade wars are, look at the recent example of American lobster fishery. In the Northwest Atlantic, where we live, we are watching the movement of coldwater species north with accelerated climate change. Nova Scotia, Newfoundland and Labrador in 2018-2019 had their highest American lobster catches ever, while Maine lobster harvests were down ~30 percent. But the markets of Canada and Maine are connected to each other, and to China. Canadian processors buy Maine lobsters, as they have different seasons and regulations. The market for live and whole cooked lobsters to China has exploded in recent years; that is, until the stupid trade wars and tariffs were put into place. With USA lobster trade to China cut, Canadian processors bought more Maine lobsters; these lobsters then acquired a "Canadian passport" and were exported to… China.

In aquaculture, the last visit we made to China was in 2018, and we witnessed aquaculture suffering in its traditional spaces from coastal urbanization and marine pollution. Aquaculture's future in China looks to be super-intensive RAS in big buildings and offshore systems outside of its polluted coastal zones. China may soon exceed the USA as the world's largest ocean food importers driven by development and the demands of its large, growing and rapidly aging middle class. At the same time, China offers many opportunities for global sustainability if radical transformation of green logistics and electrification advance rapidly.

China's development of its scientific and education institutions in aquaculture has been stunning; these offer enormous opportunities for aquaculture partnerships (and for students) from throughout the world, not only in China, but for all of us to access its deep understanding, creativity and rapid change in aquaculture. China's socio-economic and business models do not transfer well at present to aquaculture's new geographies. But the very fundamentals of our system thinking, ecological aquaculture, the ecosystem approach to aquaculture and IMTA originate in China. We have a lot to learn about China's rapidly changing "innovation ecosystem" in aquaculture (Newton *et al*. 2021).

Notes

Barry Antonio Costa-Pierce (aka "BCP", "Pierce") received a Ph.D. in Oceanography and Aquaculture from the University of Hawai'i and an M.Sc. in Zoology and Limnology from the University of Vermont. Currently he is the Henry L. & Grace Doherty Professor of Ocean Food Systems and Program Coordinator of the Graduate Program in Ocean Food Systems, School of Marine & Environmental Programs, University of New England in Maine, USA, and President/CEO of the Ecological Aquaculture Foundation LLC.

Thierry Chopin is, in 2021, celebrating 40 years of involvement in the seaweed world which he joined at the bottom of a wave during a period of "purgatory" between two "hype crests." He got his passion for seaweeds from a wonderful educator and mentor, Dr. Jean-Yves Floc'h, who also became his doctoral supervisor. It has been pretty lonely at conferences, professional meetings, university curriculum development meetings, etc. always being

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the voice saying "do not forget the seaweeds, one day you will see that they are important for many reasons" or "we need a session on seaweeds" at meetings for organizing aquaculture conferences. He has been attending conferences of the International Seaweed Association, the Phycological Society of America, and the Aquaculture Association of Canada since 1986, 1987, and 1991, respectively. He has been on the Board of Directors of each society for 12, 13, and 5 years, becoming the President of each. He also regularly presents at European Aquaculture Society and World Aquaculture Society conferences. He has been the scientific director of two large Canadian networks on Integrated Multi-Trophic Aquaculture (IMTA), an expression and acronym he first coined in October 2003. He created his own company, Chopin Coastal Health Solutions Inc., in 2016. He finds himself currently in a paradoxical situation: after promoting seaweeds for so many years, explaining the key roles, applications and services they provide, when it was not in fashion, he now has to put the brakes on and hold back a bit those with the urge to hug seaweeds (and sea cucumbers) as the planetary saviours, as professed daily on social media. Instead, he is advocating for a greener Blue Economy, the Turquoise Economy and the Turquoise Revolution (expressions he coined in September 2010), in which ecosystem services, provided by extractive aquaculture (seaweeds and invertebrates) are recognized, valued and used as financial and regulatory incentive tools through nutrient trading credits. This will lead to the progressive and pragmatic development of more diversified, efficient and societally responsible food (and non-food) production systems, within a circular economy approach, while performing bioremediation of coastal nutrification and transient decarbonization.

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